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Optimizing Denitrogenation for DCS Protection

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Introduction

Altitude decompression sickness (DCS) is caused by gas bubble formation resulting from tissue nitrogen supersaturation during decompression. Altitude DCS symptoms range from joint pain to neurological disfunction and respiratory distress. An important DCS countermeasure, other than adequate cabin pressurization, is prebreathing (preoxygenation), i.e. breathing 100% oxygen before decompression to denitrogenate body fluids and tissues. The inspiration of 100% oxygen excludes nitrogen and sets up a gradient in the tissues to allow tissue nitrogen to diffuse into the capillaries and be transported to the lungs for expiration. The longer this process is continued, the more effective the denitrogenation and the lower the incidence of DCS symptoms. The need for improvements in denitrogenation is driven by modifications in aircraft missions involving reduction or elimination of cabin pressurization, and development of new aircraft designed with pressurization systems that are inadequate to prevent DCS during some mission scenarios which the aircraft are capable of performing.

Review of AFRL Studies Relevant to Increasing Denitrogenation

From 1-4 hours of prebreathing, the plot of male DCS incidence during a 4-h, 30,000-ft exposure versus prebreathe time is nearly linear (Fig. 1; data from Webb et al., 1996; Webb and Pilmanis, 1998; Webb et al., 1999). Both linear and logarithmic best fit regressions (MSExc97 trendlines) show less than 10% additional protection for each hour of prebreathing up to four hours. After 4 hours the reduction in prebreathe effectiveness with each passing hour becomes more apparent as the logarithmic plot flattens to show only 80% protection from DCS after more than 12 hours of prebreathe. While we believe the logarithmic regression plot is too conservative, the linear regression plot depiction of a nine-hour preoxygenation as sufficient to provide complete protection from DCS at 30,000 ft (mild exercise) may overstate the effectiveness of resting preoxygenation. However, the difference between the linear and logarithmic plots with greater than 4 hours of preoxygenation is irrelevant due to the impracticability of doing an 8-12 hour prebreathe for NASA or USAF operations due to impact on crew fatigue and scheduling. Thus, alternatives to increases in traditional prebreathe time are of interest.

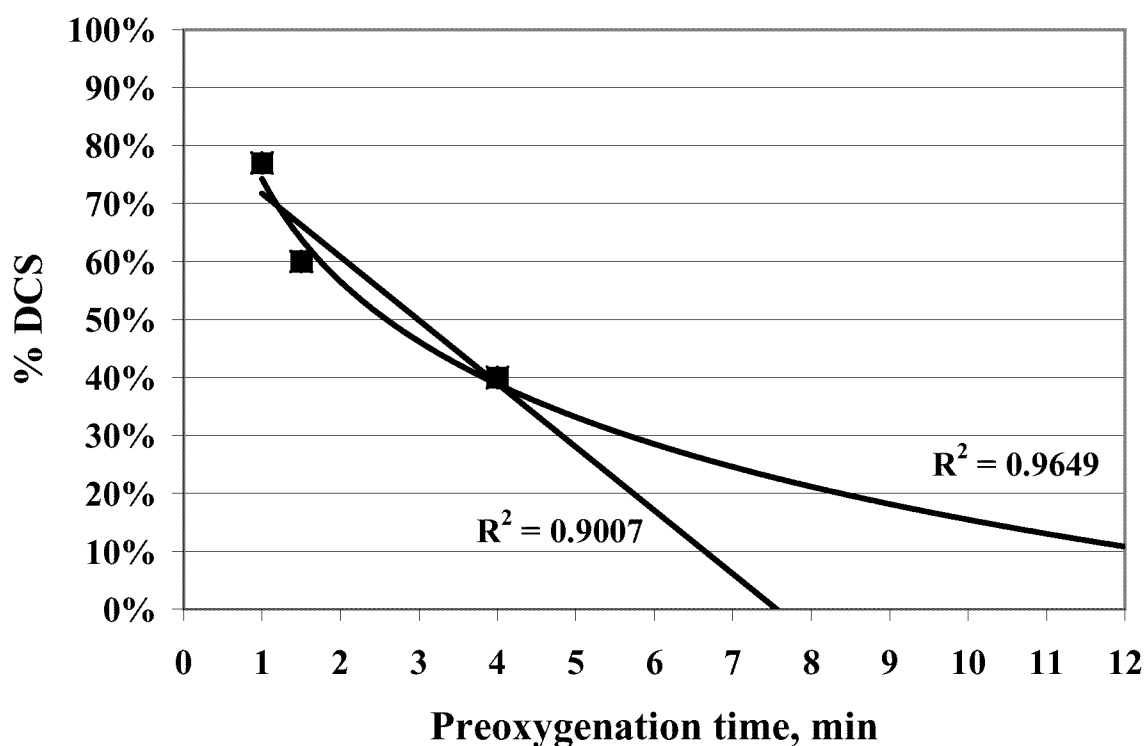


Figure 1. Preoxygenation Time versus DCS Incidence

Research in the 1950s (Marbarger et al., 1956) showed that breathing 100% oxygen during a leveloff prior to final ascent would provide additional protection relative to a continued ascent; no leveloff. Due to differences in level of symptom severity acceptable today and the advent of non-invasive bubble detection technology, we repeated the work by testing inflight denitrogenation, i.e. staged decompression while breathing 100% oxygen, at altitudes up to 18,000 ft prior to a 4-h exposure to 29,500 ft. The hypothesis was that denitrogenation accomplished at altitude is as effective as prebreathe at ground level, allowing valuable time to be saved by “prebreathing” enroute. Our work demonstrated effective denitrogenation at altitudes up to 16,000 ft prior to a 4-hour, 29,500-ft exposure (Webb et al., In 2000; Fig 2). Due to the high level of venous gas emboli and one case of DCS at an in-flight denitrogenation altitude of 18,000 ft, use of in-flight denitrogenation altitudes above 16,000 ft was not recommended.

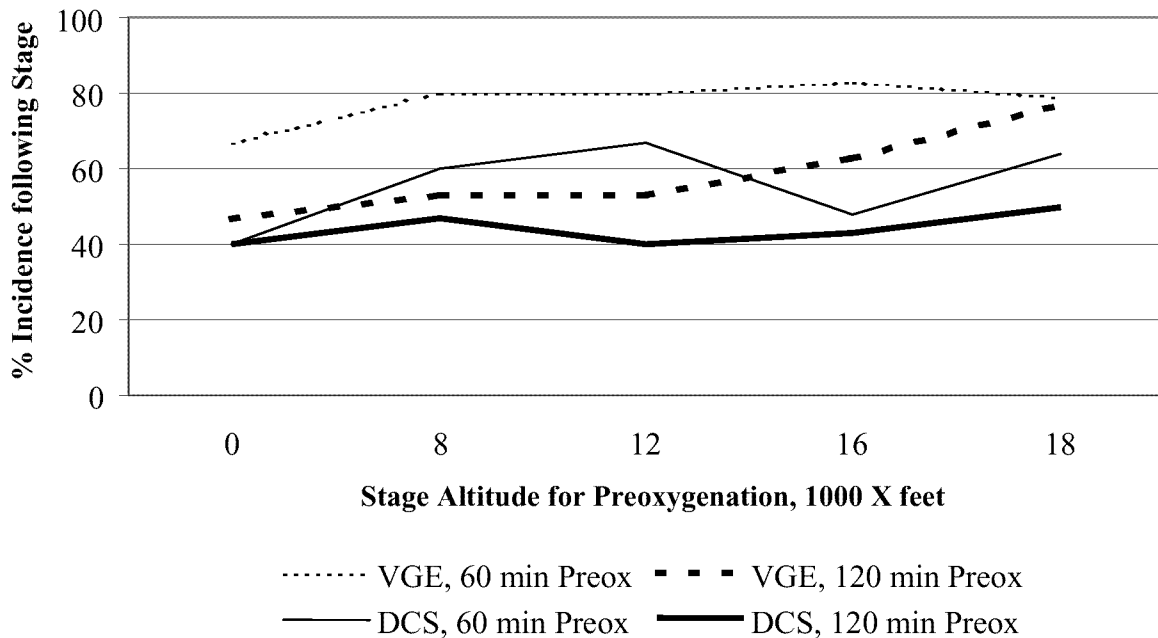


Figure 2. Inflight (Stage) Preoxygenation (Webb et al., 2000)

Another option to increasing prebreathe time is to enhance the effectiveness of prebreathe. This can be accomplished by beginning the prebreathe with 10 min of strenuous exercise, 75% of maximal oxygen uptake, that increases perfusion and ventilation. We demonstrated significant ($P < .03$) reduction in DCS incidence with this method (Webb et al., 1996; Fig. 3) and it has since been successfully tested operationally by one U-2 pilot (Webb, Hankins, and Pilmanis, 1999; Hankins et al., 2000) and incorporated in NASA's program to reduce prebreathe time prior to EVA for International Space Station construction (Gernhardt et al., 2000). Exercise-enhanced prebreathe can be used to reduce DCS incidence without increasing prebreathe time, or to reduce prebreathe time without increasing DCS risk, or, as in our study, achieve a combined reduction of both prebreathe time and incidence (Fig. 3; Webb et al., 1996; Webb and Pilmanis, 1998). Although various exercise devices were used by the U-2 pilot, the exercises all required upper and lower body aerobic exertion which did not cause significant residual fatigue (Hankins et al., 2000; Webb et al., 1999). No further symptoms have been reported by the U-2 pilot to date. However, one high flight involved a rapid response which disallowed use of adequate exercise intensity or duration. The result was DCS tolerated (unreported) for a short period prior to recovery without need for abort due to short duration of the specific mission.

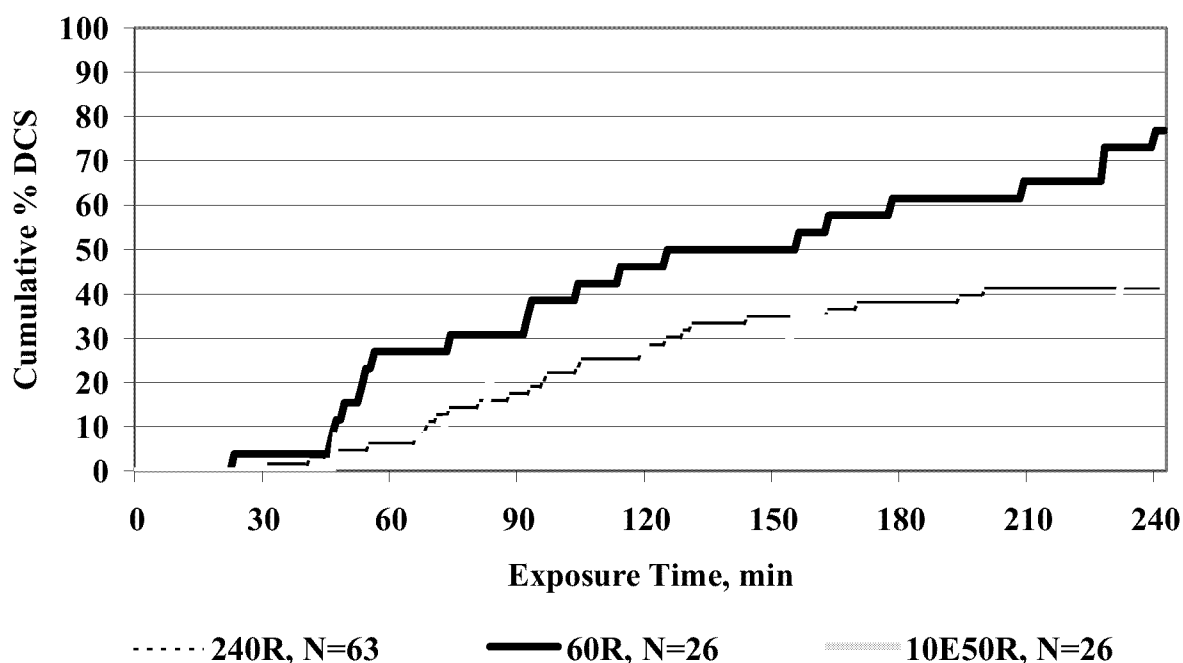


Figure 3. DCS Incidence following Resting Preoxygenation as compared with Exercise-Enhanced Preoxygenation

Comment

Continued efforts to optimize inflight denitrogenation and exercise-enhanced prebreathe should produce mission-compatible means of reducing the risk of DCS without jeopardizing mission effectiveness. These measures do require some time and equipment. The additional time and/or equipment involved with extending or enhancing prebreathe would generally not be necessary to prevent the significant altitude exposures which will be more common with development of aircraft designed with cabin pressurization systems inadequate to prevent DCS.

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